

Fine-Scale Survey of Right and Humpback Whale Prey Abundance and Distribution

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LONG-TERM GOALS

The long-term goals of this project are to describe the distribution and abundance of zooplankton prey over small spatial and temporal scales and to use this data to provide information which will be of use to scientists studying whale behavior. We are working closely with scientists studying the behavior and movement of both right and humpback whales and the combination of the two data sets will provide us information into how the behavior of marine mammals is affected by their prey.

OBJECTIVES

This project measured the abundance and distribution of the major prey species (zooplankton and nekton) of humpback and right whales as well as the spatial and temporal scales (relevant to foraging and feeding marine mammals) that the preyfield varies over. Without this information, behavioral studies of marine mammals and their responses to various stimuli may be limited in their conclusions as food presence and availability is likely an extremely strong factor in determining marine mammal behavior. In order to collect this critical information, we accomplished:

- (1) Identification of the prey type (e.g. copepod, krill, fish) and numerical abundance of zooplankton and nekton in the vicinity of marine mammals by integrating multiple frequency acoustic survey data with net and video measurements (Foote and Stanton, 2000; Warren et al., 2003). The distribution and numerical density of prey (in both the horizontal and vertical dimensions) relative to predator presence and behavior was measured. We measured the variability of the preyfield over length and time scales (1 m - 10s km, 10 sec - days) that are important for right and humpback whale feeding behavior and success.
- (2) Measure environmental parameters (hydrographic and meteorologic) during these surveys that may be correlated with marine mammal behavior, the presence of prey species, or sub-surface acoustic scattering processes (Warren et al., 2003; Lawson et al., 2004).
- (3) Collect visual observations of surfacing marine mammals and their behavior during the survey which can be integrated with the preyfield data and observations from other vessels or instrumented tags.

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APPROACH

Acoustic Surveys

Acoustic backscatter data was collected continuously from a research vessel in the same area as that of the tagging operations. Multiple frequency acoustic data were used to discriminate between different types of scatterers in the water column with the primary distinction being between zooplankton (primarily copepods in this area) and nekton (small fish such as sand lance or herring). The general approach is to conduct a regular grid-like survey while our collaborators are attempting to tag a whale. Once a whale is tagged, then the vessel will follow the whale (as best as possible) so that we can describe the preyfield that the tagged animal is experiencing.

Net Tow Sampling

At regular intervals during the survey operations, we conducted vertical net tows to identify the species of interest that occur in the water column as well as to provide information necessary to convert the acoustic data into estimates of biomass density (mg/m^3) or numerical abundance ($\# / \text{m}^3$). At each station, a vertical net tow to a depth of 5m is conducted and when time permits we also conduct net tows to 1 m depth and the shallower of the full water column or 20 m depth. This sampling allow us to determine if there are differences within the water column in either the type or abundance of zooplankton present. Additional measurements include the use of a video camera system to collect in situ information about animal (specifically fish species) identification and orientation in the water column.

Hydrography

At the net tow sampling stations, hydrographic data are collected with a SeaBird 19+ CTD. This sensor provides information on temperature, salinity, density, dissolved oxygen, and fluorescence at a vertical resolution of 10s of cm for the water column. These data are particularly useful in determining if there are physical or biological factors that may affect the distribution and abundance of zooplankton prey in the water column.

Surface Observations

During transit, survey, and station; surface observers record the presence, distance and bearing (estimated), abundance, species, and behavior (when possible) of any marine mammals near the vessel. These data are collected to supplement the observations made by our collaborators and will provide us with a larger data set of predator observations to relate to our prey information. In addition, the observers record basic weather and sea state information.

WORK COMPLETED

We completed our final field season during spring 2010 with the research vessel and field team based out of Provincetown, MA for a three week period from March 25th to April 17th. Acoustic backscatter data were collected from a towfish (equipped with 38, 120, 200, and 710 kHz scientific echosounders and a 600 kHz Acoustic Doppler Current Profiler) deployed from the starboard side of the RV Stellwagen. Two modes of survey were used: standard straightline transects or animal-specific surveys around 'D-TAG'ed baleen whales. In addition to the acoustic transect data, we completed 15 CTD stations, 54 zooplankton net tow stations, 12 video plankton recorder stations, several water sample collections for bulk chlorophyll analysis, and several hundred surface observations of marine mammal predators (primarily humpback and right whales). The majority of survey operations occurred during the day, although we did conduct one overnight study. Since the conclusion of the field work aspect of

the project we have accomplished: complete analysis (species identification and enumeration) of all net tow samples; analysis of the spatial and temporal variability of the acoustic backscatter data, and in conjunction with our collaborators, we have correlated right whale location in the water column with the distribution of copepods measured acoustically which has resulted in a high-profile, peer-reviewed publication (Parks et al., 2011) in the journal *Biology Letters*.

RESULTS

* Net and video data indicate that near foraging right whales, small copepods were the dominant zooplankton and were concentrated in the upper 5 meters of the water column. Video data indicate that near foraging humpback and fin whales, herring and sand lance were the dominant acoustic scatterer and were found at various depths. (Figure 1)



Figure 1. Multiple net tows (VS [0-1m], S[0-5m], D[0-20m]) to different depths at stations near right whales showed that near-surface (0 to 5 m) waters contained the majority of zooplankton (left). The zooplankton were primarily small (1.5 mm mean length) copepods (*C. finmarchicus*). Near feeding fin and humpback whales, small fish (sand lance (shown escaping a lunging fin whale) or herring) were the dominant acoustic scatterer (right).

Copepods were the primary zooplankton in the water column in Cape Cod Bay although the biomass varied spatially both horizontally and vertically. At most zooplankton stations, multiple tows were conducted (Figure 2): a 1m very shallow (VS) tow, a 5 m shallow (S) tow, and a 20 m deep (D) tow. In general, numerical densities of copepods were similar between the shallow and deep tows suggesting that most copepods were found in the upper 5 m of the water column. We have completed the identification and enumeration of all of our zooplankton samples from this project (111 net tows total) before the end of the grant which is a first for my laboratory! Typical numerical densities were between 10^2 and 10^5 individuals per cubic meter. In general, samples from Cape Cod Bay were small (mean length 1.5 mm) *Calanus finmarchicus*, which ranged from 30-80% of the total copepod abundances numerically. We also deployed additional video samplers to supplement the net and acoustic data. A Video Plankton Recorder (VPR) was used to collect vertical profiles of the

zooplankton in the water column while an underwater video camera was deployed to determine the identity of nekton scattering layers that were found.

* Acoustic backscatter data show that small scatterers (copepods) were concentrated near the surface. We can quantify abundance which varies over small (10s to 100s of meters) horizontal distances and relate these to the distribution and behavior of tagged right whales. (Figure 2)

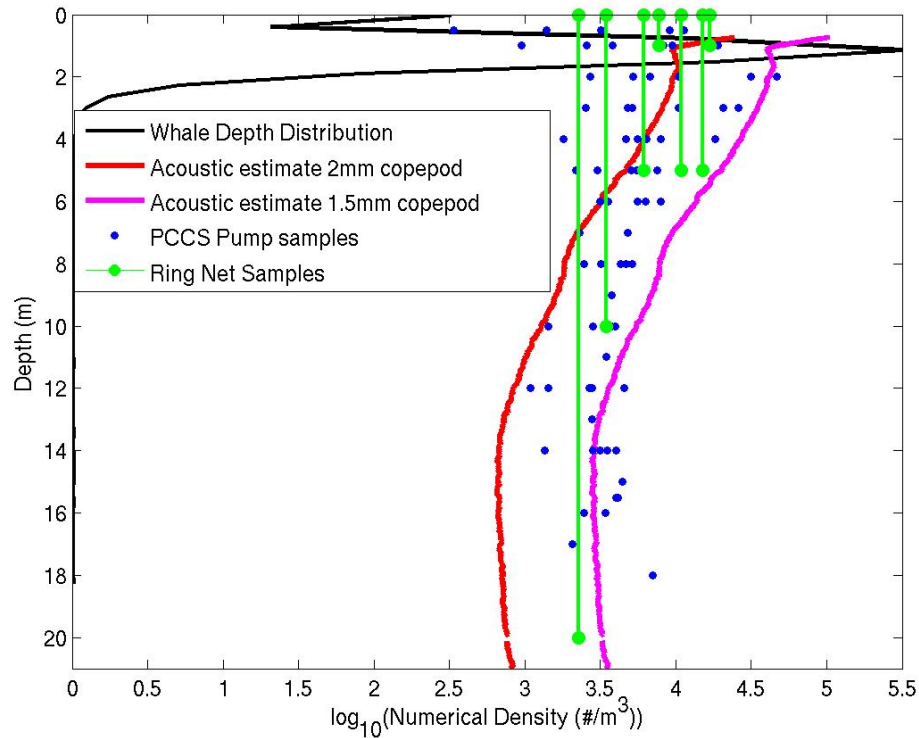


Figure 2. Depth distribution of a tagged right whale (rw095) relative to quantitative measurements of copepod numerical density from nearby net tows (green lines/circles), pump samples (blue dots, data courtesy of Provincetown Center for Coastal Studies), and acoustic backscatter measurements converted to numerical density using two size classes of copepods. There is very good agreement with the copepod numerical densities from the three different sampling methods and the peak copepod abundances occur at the depth where the right whale spends the majority of its time.

Animals a few mm in length can only be detected acoustically at high frequencies. Both our 600 kHz and 710 kHz acoustic systems showed high levels of scattering in the very near surface waters. It is important to note that other near-surface scattering processes such as bubbles can be strong acoustic scatterers (at all frequencies). By comparing the data from our lower frequencies (38, 120, and 200 kHz) and our higher frequencies (600 and 710 kHz), we are able to determine that zooplankton and not other scattering processes are responsible for the near-surface scattering that was observed. We developed an estimate for the Target Strength of the copepods found in these waters so we could convert our acoustic data to estimates of numerical density that are important for animal foraging energetic studies.

* Acoustic data show that in other areas, nekton (herring or sand lance) were the strongest scatterers in the water column. (Figure 3)

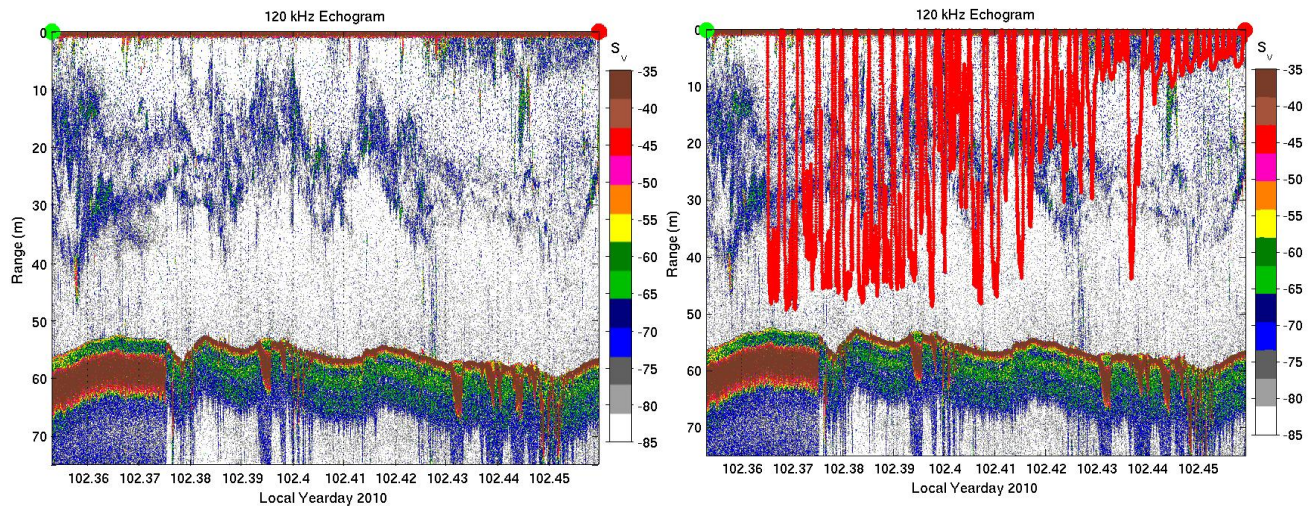


Figure 3. 120 kHz echogram (left panel) shows schools of small fish (identified by video methods as herring) distributed between 10 and 40 m depth initially, then the schools shift their distribution to being in the upper 10 m of the water column. These data were collected concurrently with a tagged humpback whale (mn102a) whose dive track (red line, right panel) shows that the whale's dive depth behavior is closely related to the distribution of their prey and that changes in the prey distribution cause a change in whale dive behavior. [Whale data courtesy of S. Parks]

Acoustic backscatter data from multiple frequencies can be used to identify and discriminate between different acoustic scatterers. When scatterers are different sizes (copepods, fish), this can be done by examining whether backscatter at lower frequencies is similar (fish) or less than (copepods) than the backscatter at high frequencies. We discriminate (acoustically) between the two dominant nekton species (herring, sand lance) that were encountered during this study by examining the differences in backscatter at multiple frequencies as well as by the behavior of the scattering aggregations. Video data were used to identify the scatterers for some aggregations.

* Location and behavior of right and humpback whales are related to the presence, location, and density of their preferred prey. (Figure 4)

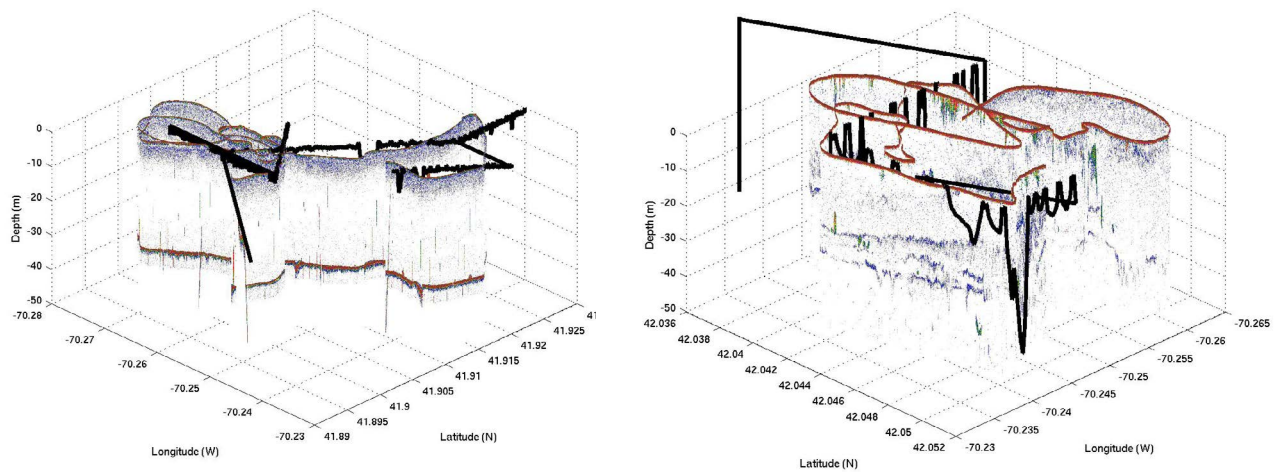


Figure 4. Three dimensional maps of prey field and tagged predator movements. Tagged right whale movement (black line) overlaid with the 710 kHz echogram (representing copepod abundance) shows that the right whale spends most of its time at or within 3 m of the surface (left panel). Tagged humpback whale movement (black line) overlaid with the 120 kHz echogram (representing fish abundance) shows that the dive behavior of the humpback whale follows closely the depth of the fish schools (right panel). The whale movement is assumed to be a straight line between surface observations and Dtag GPS position locations. We are in the process of georeferencing the Dtag acceleration data to produce full 3-D representations of whale movement within the preyfields measured acoustically. Both panels show an area 2 km x 2 km and 50 m deep.

By combining acoustic backscatter data from surveys conducted around tagged baleen whales, it was found that the whale's location and behavior were related to the abundance and distribution of their prey. When possible, our instrument was towed near to a tagged animal. If the animal was transiting, we would follow the whale at a distance of about 100 m. If the animal was not moving quickly or moving back and forth, we would move in a large circle with the whale at the center. These data allow us to measure what the preyfield was close to the tagged whale. We wanted to avoid having the presence of our vessel and echosounder affect the behavior of the tagged animal so our data are not co-located (in time or space) to the tagged animal, but are (generally) collected within 150 m and a minute or two of the whale passing through a particular area. Given the variability in the preyfield that we measured, we can estimate how accurate our estimates of the preyfield are in terms of the difference between the whale and our measurement locations.

Using D-TAG data provided by our collaborator (Susan Parks, Penn State), we can create two- and three-dimensional figures showing the behavior of the whale and an approximation of its preyfield. For right whales, copepods are the prey species and were found in the near surface which is also where the whales spent the majority of their time. For humpback whales, fish (herring or sand lance) are the preferred prey. The vertical distribution of nekton varied spatially, and the behavior of the humpback whale changed as the prey distribution did. We are currently developing metrics that best quantify how these two factors (prey density, predator behavior) are inter-related. It is interesting to note that the different behaviors of the tagged whales are both correlated with the presence of their prey. And that

the tagged whale behavior can be very consistent (in the case of the right whale) or vary quite a bit (as in the case of the humpback whale). It should be noted that we have a fairly small sample size from this study.

IMPACT/APPLICATIONS

The data collected in this project forms the basis for understanding the prey environment that right and humpback whales encounter in these regions. In order to assess marine mammal behavior, an understanding of the distribution and abundance of their prey will be critical to understand their feeding behavior. We describe the spatial (both horizontal and vertical) and temporal patterns that occur in the prey (zooplankton and small nekton) for these two species in conjunction with scientists measuring the movement and behavior of these animals. When there are patterns that exist in the whale's preyfield and that the behavior of the whales is correlated with these patterns then that information will be useful for a variety of purposes including a better understanding of the foraging ecology of right and humpback whales and the processes that affect their behavior and movements which can assist conservation efforts and the mitigation of anthropogenic impacts on these animals.

RELATED PROJECTS

This project works closely with the Parks/Wiley project "Fine-scale Focal Dtag Behavioral Study of Diel Trends in Activity Budgets and Sound Production of Endangered Baleen Whales in the Gulf of Maine" to coordinate field activities and logistics, sampling plans, and data analysis. The 2009 and 2010 field seasons were a success in terms of coordination of the sampling for this and the Parks/Wiley project in that concurrent data were collected on the zooplankton populations and their marine mammal predators. We have already published one co-authored, peer-reviewed publication and anticipate several more joint-authored publications to result from this project and have several of these in manuscript form. In addition, we coordinated our sampling with that done by the Provincetown Center for Coastal Studies in Cape Cod Bay in order to measure the zooplankton populations over a larger spatial area than we could by ourselves.

PUBLICATIONS

S.E. Parks, J.D. Warren, K. Stamieszkin, C.A. Mayo, D. Wiley (2011) "Dangerous dining: surface foraging of North Atlantic right whales increases risk of vessel collisions." *Biology Letters*. doi:10.1098/rsbl.2011.0578 [published, refereed]